IX.—The Ice Question—as it affects Canadian Water Powers—with special reference to Frazil and Anchor Ice.

By John Murphy, E.E.

(Communicated by Dr. Barnes and read May 27th, 1908.)

Canada's Water Powers are daily becoming more and more intimately associated with our daily life because to-day's necessities in the forms of abundant supplies of water for domestic, industrial and fire-protective purposes, and electrical energy for light, heat and power purposes are, to a great extent, dependent upon them. Canada's severe winters have always affected her Water Powers and on this account it has become the custom to couple the Ice Question with discussions relating to Water Powers in this country.

The following study of the Ice Question with special reference to Frazil and to Anchor Ice is presented in the belief that the difficulties which these forms of ice have caused may be entirely overcome.

It is well known that the industries and services which are dependent upon water power for their operation have been frequently interrupted by ice. It is also generally believed that water powers in this country will never be immune from ice troubles. The ice that is usually most troublesome at Canadian hydraulic power plants is called frazil, but it is more often improperly called anchor ice. At the outset it may be well to say a few words about anchor ice and then dismiss it from this discussion altogether.

Anchor ice grows on dark rocks on the bottom of uncovered streams when the earth is losing heat by radiation. While attached to the bottom—anchored there by adhesion to the rocks and not by its weight, because it is lighter than water,—it resembles wool on the backs of sheep. "The French-Canadian expression (for anchor ice) is *moutonne*, as it "resembles the white backs of sheep at rest." This quotation is from Dr. H. T. Barnes' book called "Ice Formation," page 106, and to those who wish to study the ice question thoroughly I beg to recommend this work. Anchor ice is feathery or woolly stuff through which a pole or rod may be pushed. While still attached to the bottom of streams where it forms and grows it is tenacious and gathers to itself particles of ice which float against it. So long as anchor ice remains upon the bottoms of uncovered streams, where it has formed, it is evident that it will cause no inconvenience to power plants unless it actually forms a dam and prevents the water from passing the latter. As an illustration

of its adhesive nature it may be mentioned that it sometimes grows up the outer face of a waterfall over which large rocks are carried by the swift running water. Anchor ice forms upon the rocks when the sun is not shining and in this respect, as well as in appearance, it is like frazil. When the sun's rays impart a minute amount of heat to water under which anchor ice has grown the latter loosens its grip upon the bottom and rises to the surface. It then floats, as a mass of snow would do, almost entirely submerged, but with no trace of the inclination which it possesses at the bottom to cling to other objects. In this condition, if the masses are broken up, it will readily pass through hydraulic power plants with the water which operates the latter.

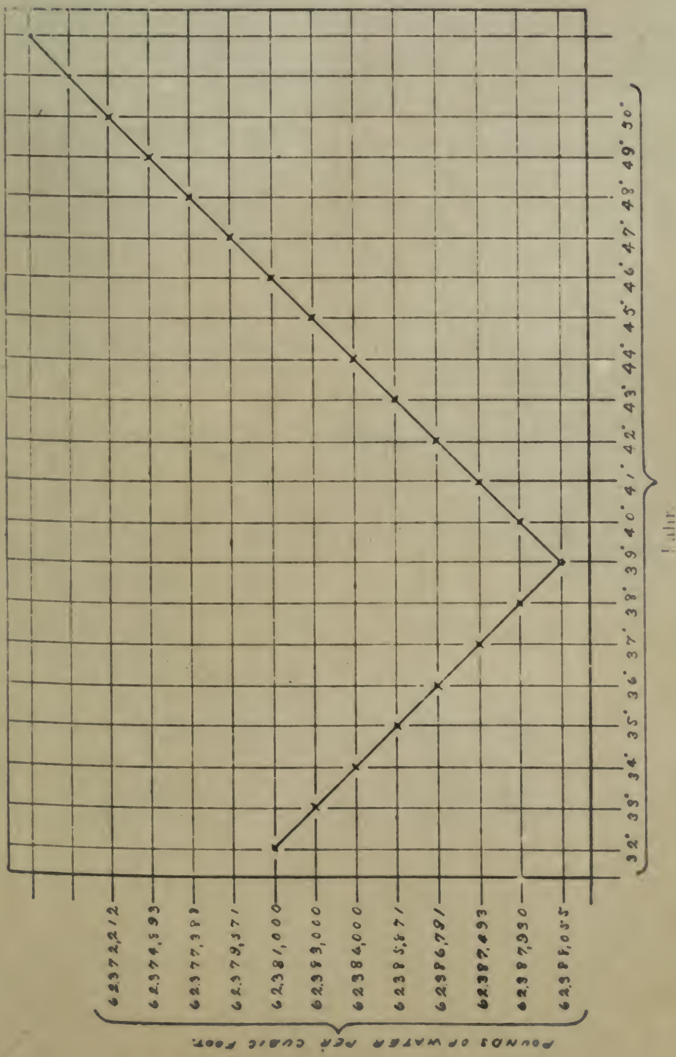
Frazil which is really the bugbear of water power plants is formed in an entirely different manner. Frazil forms upon the surface of water and it would be unknown if the surfaces of canals, streams and lakes remained smooth when winter was setting in. When these surfaces are disturbed, however, by the wind, or by the current, or in rapids, the icy spicules, into which the tops of the waves and the spray of water are turned, are prevented from uniting together and forming a sheet of ice. These spicules are known as frazil. Frazil forms most abundantly in open rapids which never have a protective covering of sheet ice, but it also forms upon the surface of any body of water—such as a lake or a canal—if the water's surface is disturbed by any cause which retards or prevents sheet-ice from forming. As Canadian winters are usually borne in upon the wings of a cold northwest wind, which roughen the surface of the waters, it is not uncommon to see hydraulic plants shut down by frazil, although situated at a supposedly immune-from-frazil location. Two notable examples in line with this contention may be cited: One of these is at the hydro-electric power plants, at Deschenes, Quebec,—just across the river from Ottawa's summer resort, Britannia Bay,—and, the other is at the Water Works Pump House of the City of Montreal. Frazil has often shut down both of these works. One has a stretch of 25 miles of *smooth* lake and river above it, and the other has many miles of *quiet* canal for a head race. The terms "*smooth* lake" and "*quiet* canal" are only applicable to these, or any other bodies of water, when the wind is not blowing.

Frazil, then, is likely to form upon the surface of any body of water when the latter is not protected from the action of the cold air by a layer of sheet or surface ice, or by some artificial covering. After surface ice is once formed frazil is made in open rapids only, and it does not then enter power plants because it clings to the surface ice under which it may be carried by the current. If the surface ice is removed by a

Fig. 1a.

Weights of water at various temperatures.

(From Suplies Mech. Eng.)



temporary spell of mild weather frazil will form again upon the return of cold weather—in the same manner as it does in the early part of almost every winter.

One of the many remarkable properties of water is that it is lighter when its temperature is just at the freezing point than when its temperature is at any other point within 7 degrees of the freezing point. This peculiarity is illustrated in Fig. 1*a* in which layers of water at various temperatures would take up the respective positions shown. Ice floats on water and it may be noted also that water at the freezing point would rise to or stay at the surface and form a protective covering for the main body of water if the surface were left undisturbed. The conditions illustrated in Fig. 1*a*, however, are not usually allowed to obtain—they are upset by the boisterous winter wind, by rough rapids and by the greedy power users who are rarely content to let the water flow along towards their water wheels in a smooth quiet manner.

The Ottawa District has become famous, amongst the engineering profession, as a frazil-manufacturing centre. Why it has achieved this reputation may be learned by a study of that portion of the Ottawa River—Fig. 1—from which most of the energy used in the district comes.

The hydraulic power plants in this vicinity are nearly all situated at the Chaudiere Falls at Ottawa and Hull. As may be seen in Fig. 1 these power plants are below three sets of rapids. There are also a few power plants at Deschenes—just at the Deschenes Rapids.

Your attention is specially directed to the fact that the Deschenes plants, although having no rapids or water-falls above them, for 25 *miles*, are placed *hors de combat* almost every winter by frazil. This is explained as follows:

'A cold northwest wind is the harbinger of winter. This wind, crossing it as it does, lashes and furrows Lake Deschenes and prevents sheet-ice from forming on its surface. A tremendous amount of frazil—the ice spicules which would soon unite and become sheet-ice but for the disturbing action of the wind—is manufactured *in Lake Deschenes* itself *before* the rapids are reached at all! The sides and the bottom of the outlet of Lake Deschenes are so rough in character that the velocity of flow at the *surface* is perhaps greater than at any other portion of the stream. On account of this great surface-velocity much of the frazil formed on the surface of the lake is drained through its mouth and into the power plants. The water in the rapids is of course kneaded—as a baker kneads dough—from top to bottom and bottom to top and new water surfaces are being continually turned up and subjected to the cooling action of the air. The temperature of the water at this rapid, in-

Fig. 1.
A View of the Ottawa River near Ottawa

stead of remaining warmer at the bottom, as it would if the stream were quiet—as shown in Fig. 1*a*—is thus mixed with the frazil and probably wholly reduced to the ice-making temperature. Under favourable atmospheric conditions the Ottawa River becomes a stream of frazil instead of water. The "kneading" and spray-crystallizing procedure is enacted again and again in the two other rapids, en route to the power plants at Ottawa and Hull. With a knowledge of the above conditions it is not surprising that the water power plants near Ottawa encounter frazil troubles. The destruction of rapids, by the erection of dams, will prevent the continuous—all winter—formation of ice spicules, or frazil, but the impracticability of shielding the surfaces of long open water reaches from the action of the early winter wind is quite apparent and the frazil question will, in my opinion, always demand some attention at water power plants.

Frazil attacks are *never* experienced at hydraulic power plants when the sun is shining, but they may be expected—under favourable conditions—at any other hour of the day or at night. While the sun is shining it imparts enough heat to the water to prevent frazil from being formed. Frazil has the peculiar tendencies of growing in the water and of clinging to everything with which it comes in contact. It has on several occasions within my own observation temporarily choked up the total flow of the Ottawa River by blockading the rapids. A view of a rapid blockaded by frazil and anchor ice is presented in Fig. 2 through the kindness of Mr. J. B. McRae, C.E., who also supplied photographs 5 and 6. The newspapers last winter stated that anchor ice caused the St. Lawrence River to rise 25 feet and flood a portion of the town of Cornwall, Ont.

It is this tendency of frazil to cling to other objects and to form itself into impervious masses that makes it cause so much trouble at power plants. Instead of flowing quietly through a power plant, as water does, frazil clings to the edges of every opening, thus reducing their areas, and often closing them altogether. Large rectangular sluices, 6 feet long by 3 feet wide, have been blocked by frazil so completely in a few hours that a drop of water could not flow through them.

One of the earliest attempts to cope with the frazil difficulty, which came to my notice, was the hanging of cedar boughs from a stout rope stretched across the surface of a channel. This was done by grist millers many years ago, and the cedar bough barrier floating in the water soon became covered with frazil and served as a starting point for the formation of surface ice. The idea was a good one, but as these barriers soon formed dams which were torn from their moorings by the force of the water, and the whole mass was sometimes carried into the racks at the

FIG. 2.—RAPIDS ON OTTAWA RIVER CHOKED WITH FRAZIL AND ANCHOR ICE.

power plants, this practice was not universally adopted as a positive or reliable preventive of frazil troubles. It was sometimes harder to remove the cedar boughs from the racks than the frazil.

Seeing water works, electric light and railway systems annually shut down by frazil for many years and being very much interested in their continuous operation, I made many attempts to ascertain just when frazil attacks might be expected. I obtained data from the meteorological bureau at Toronto in regard to barometer and thermometer readings, as well as records of the direction and velocity of the wind, and such other atmospheric conditions as might have any bearing upon the subject of frazil formation. A review of these data, when tabulated, showed that frazil attacks occurred on some occasions when the temperature of the air was only 4 or 5 degrees below the freezing point and at other times when the temperature was 30 or 40 degrees below the freezing point. Severe cold alone did not seem to cause frazil to form. Besides showing great air temperature variations these data also showed that frazil attacks were invariably accompanied by a northwest wind. This last point was the only one, so far as we could see, which seemed to have any material or direct bearing upon the frazil question. We then turned our efforts to the task of recording, several times daily, the temperature of the water itself, and from this work we at last become able to foretell to a certainty, a few hours ahead, when frazil would arrive. We found that as soon as the temperature of the water was lowered to within one degree of the freezing point "trouble" was at hand, and we also found that the time of the lowering of the water's temperature to the freezing point was the time when frazil was made if a northwest wind was blowing. Fig. 2*a* illustrates this point.

Fig. 2a shows how gradually the temperature of the water reaches the freezing point—32° Fahr.—after many days of cold weather, and that it remains just at the freezing point until warm weather sets in. Frazil is formed at the time the temperature of the water falls to 32° Fahr.—in this instance on Dec. 3rd.

We found, further, that the temperature of the water in the river remained exactly at the freezing point during all the rest of the winter. An exception to this rule sometimes occurred when an early cold spell in November was succeeded by mild weather; under the latter condition the water's temperature was raised a degree or two and when this happened another attack of frazil was to be expected when cold weather set in again. Our water temperature measurements were made with a mercury thermometer, and I wish to emphasize this point in order to explain what may otherwise look like a discrepancy between the results

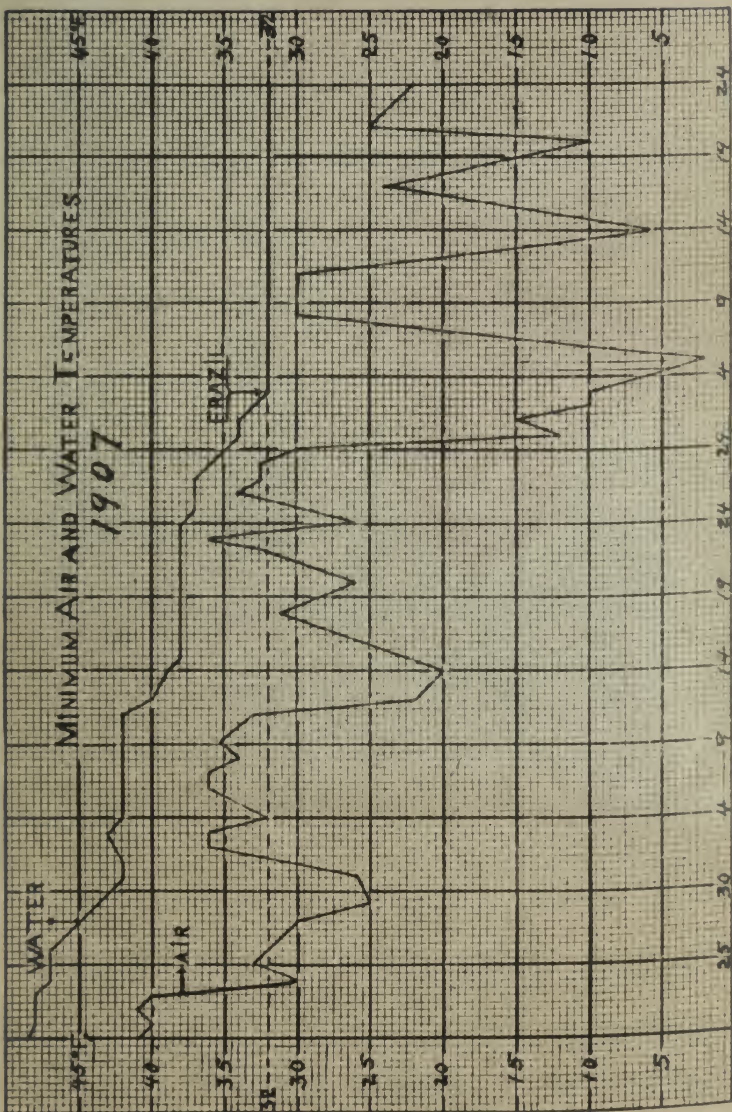


FIG. 2a.

Fig. 2a shows that frazil was formed on Dec. 3rd when the water's temperature reached 32° Fahr.

of our crude work and the accurate and excellent work of Dr. Barnes to which I refer below.

Now that we have seen how and when frazil is formed a view of a water power plant—as in Fig. 3—may assist in obtaining a better understanding of the troubles which frazil causes to it.

Fig. 3 is a sectional view of a horizontal water-wheel and wheel-pit. A is a view of one bar of the rack, or screen, which prevents floating debris from being carried into the penstock or wheel pit. The rack bars are set at a slight angle for cleaning or raking purposes. The dis-

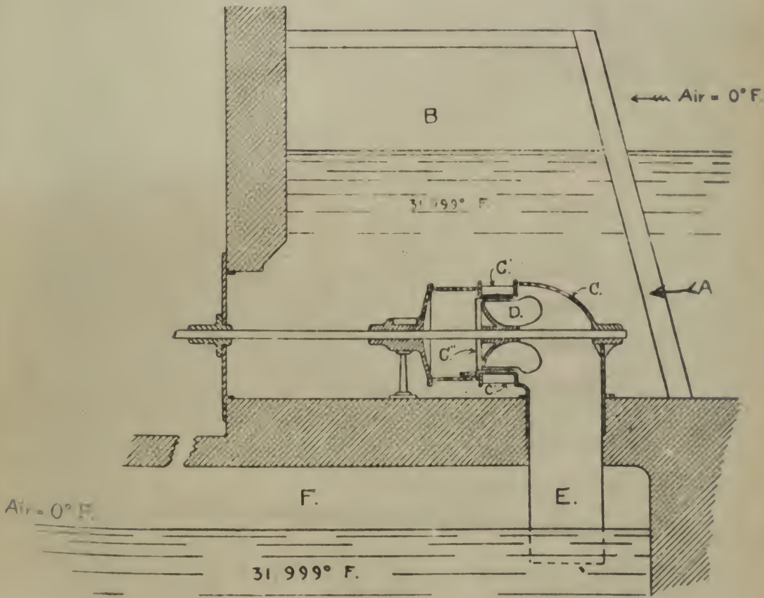


FIG. 3.

tance between these rack bars varies from 1 to 3 inches according to the sizes of the openings in the wheels which they are to protect.

B is the wheel-pit in which the complete water-wheel outfit is set up.

C is the wheel case in which the water wheel or turbine D runs.

C' C' are the chutes between which the water passes as it enters the wheel.

C'' is a cylinder gate by means of which the water-wheel is started, stopped and controlled by varying the length of the opening between the end of the gate and the wheel case and thus controlling the amount of

water passing through the wheel. The gate has rods attached to it—not shown—which pass out into the generator room and are connected with the controlling mechanism.

D is the turbine or "runner" as it is called. It is keyed solidly to the shaft, which projects into the generating room—if this happens to be a hydro-electric station. A coupling unites this shaft to the generator shaft, or a pulley mounted upon this shaft will drive machinery of any character.

E is the draft tube through which the water flows or falls into the tail race, and being air-tight it enables the turbine to operate under the total head of a water fall even though the turbine is not situated at the exact bottom of the fall.

F is the tail race which is simply a channel for the purpose of carrying off the water after it has done its work of driving the machinery.

A power plant of this character suffers from frazil in the following manners:—

(1) The openings in the rack get clogged, and, as the supply of water is reduced, so is the output or capacity of the plant lessened. When rack-clogging once begins a complete shut down is usually inevitable within a very short period of time. Some institutions, believing a shut down unpreventable in any other way, entirely remove the rack just before winter sets in. Their water-wheels then run the risk of being destroyed by floating debris, but this *risk* is, in their opinion, preferable to the *certainty* of rack clogging and a shut-down. Hand and mechanical rakes are used for the purpose of removing frazil from racks. The raking simply consists in scraping the frazil from the bars and, when it is scraped off, the current carries it against the rack again or into the wheel-pit. If a side sluice exists near the end of the rack much of the frazil may be floated over it.

Some idea of the amount of work required to keep a rack open during an attack of frazil may be gathered when I say that the combined efforts of two motor-driven rakes and a gang of willing able-bodied hand-rakers, placed so close together that they elbow each other, are often unable to keep a rack half open. Fig. 4 shows the front of a rack with a motor-driven rake at the left of the picture, and Figs. 5 and 6 give only a faint idea of the amount of frazil which is sometimes encountered.

(2) When the rack is kept open by raking, the next difficulty that is encountered is the sticking or freezing of the water wheel's controlling gate. The frazil clings to the chutes and to the exposed part of the gate and it cements the gate so firmly to the parts of the wheel case which surround it that the gate cannot be moved. The wheel in this condition

Fig. 4.—Motor-Driven Rake Mounted upon a Track on the Platform Above the Rack.

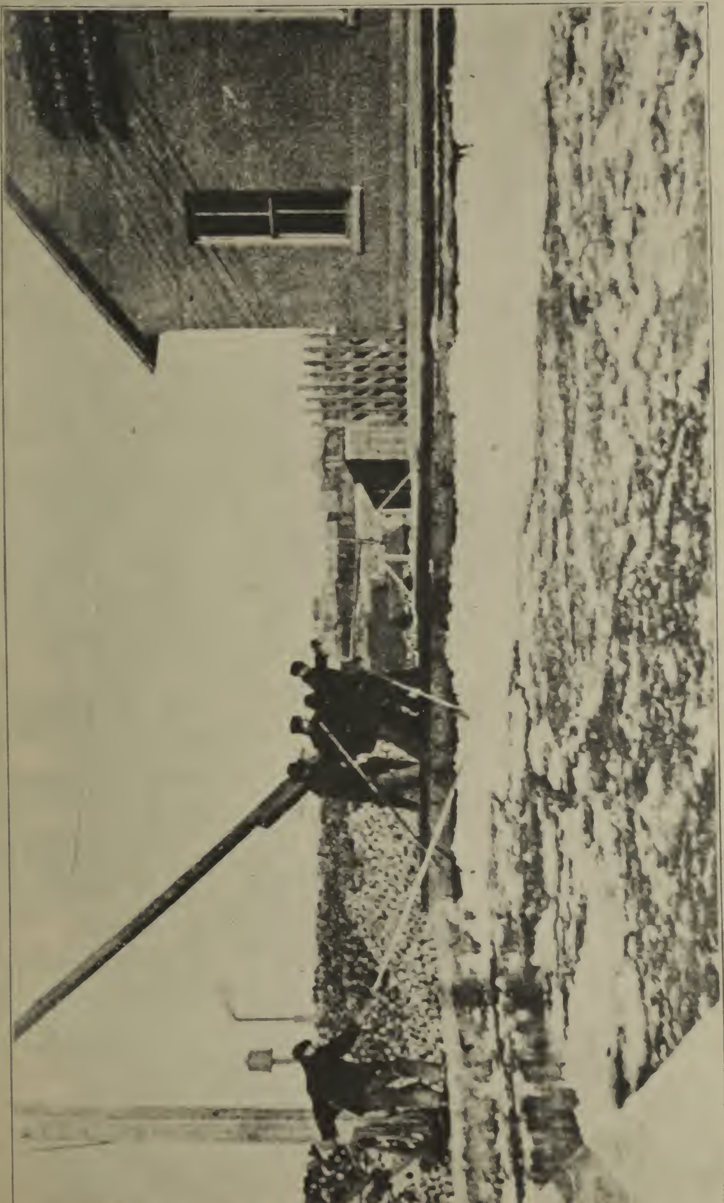


FIG. 5. WORKMEN REMOVING FRAZIL FROM FOREBAY OF POWER PLANT SHUT DOWN BY FRAZIL.

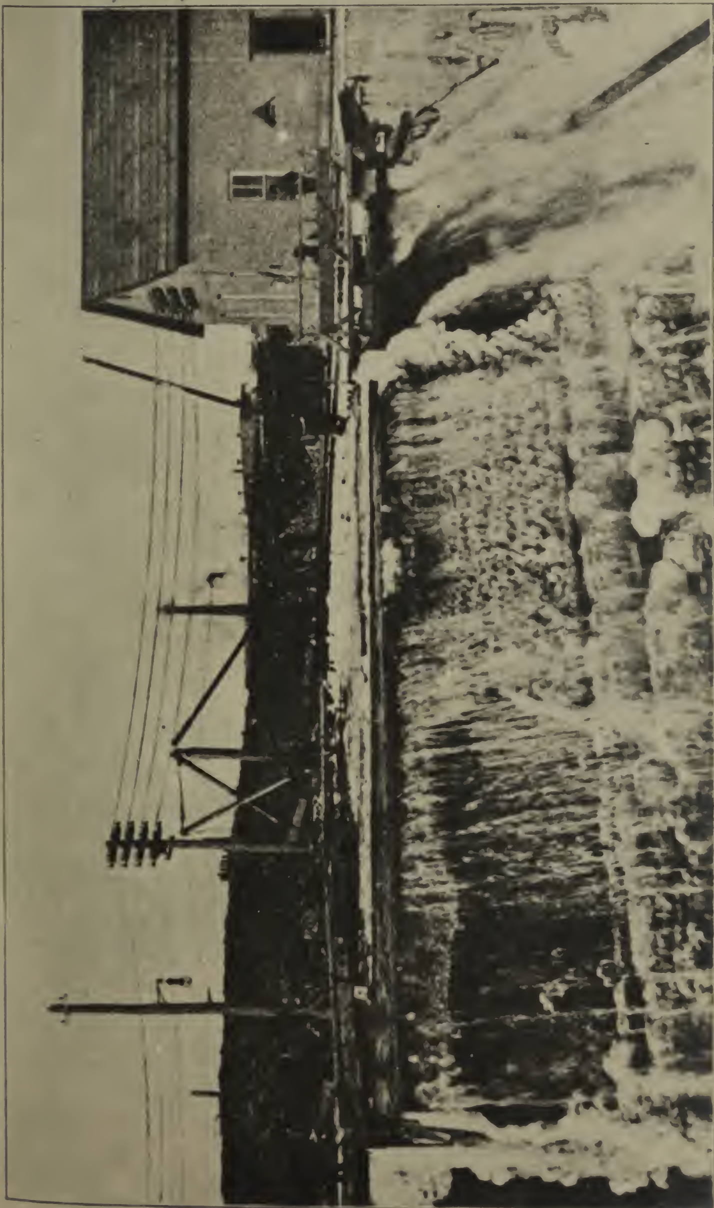


FIG. 6.—FRAZIL AND WATER FLOWING OVER SPILLWAY AT PLANT SHUT DOWN BY FRAZIL.

FIG. 7.—FRAZIL-CLOGGED RACK CLEANED BELOW THE WATER LINE BY A SLIGHT INCREASE IN WATER TEMPERATURE.

becomes uncontrollable! The automatic governors, although very powerful machines, are *not* capable of loosening frozen gates from their icy grip and heavy gearing is often broken in the attempt. It is a common occurrence to see steel pinions having large factors of safety, so far as mechanical strength is concerned when doing their ordinary work, torn apart while an effort is being made to loosen water wheel gates which have become fastened to the wheel cases by frazil. The freezing of the controlling gates of a water power plant is a more serious matter than is generally realized; a plant might, in this condition, be compared to a runaway locomotive but for the fact that the locomotive, awful though its destructive capabilities may be, *cannot* do nearly so much damage as the runaway power plant. The energy of the locomotive is reckoned in hundreds of horse power while the power plant's capacity is usually measured in thousands! The fire may be drawn, or, it will soon die out under the boiler of a runaway locomotive, but a river is not likely to stop its flow within the same time-limit. If the load which is being carried by a power plant falls off while the controlling gates are frozen to the wheel-case disastrous electrical and mechanical breakdowns may follow. One not intimately acquainted with these conditions can scarcely imagine the serious plight in which a power plant and its attendants are placed when the controlling gates become frozen tight and the speed of the apparatus gets beyond control.

(3) The third difficulty to which frazil subjects a power plant is the clogging up of the water-wheel chutes. The effect of ice closing up the chutes is just the same as closing the gate and a complete shut-down is thus effected.

The top part of the rack, in Fig. 7, to which frazil is clinging may convey some idea of the manner in which frazil will plaster up a rack and prevent water from entering the wheel pits or penstocks. All the mills and power houses in the Ottawa district were stopped by frazil on the occasion when this picture was taken and, as the water in the head races arose when the plants were stopped, this accounts for the height to which the frazil ascended this rack. Frazil covered every portion of this rack from top to bottom to such an extent that not a drop of water could pass through it. When this picture was taken, the plants were all again in operation and the water in the forebay had dropped to its usual height. The sun had relieved this plant. This rack faces the South. Racks facing the North freeze up more quickly and remain frozen longer. This valuable point seems to appeal more strongly to greenhouse designers than to the designers of some water-power plants.

Attention is directed—in Fig. 7—to the manner in which the water had cleaned the frazil from this rack at and below the water line although the temperature of the air when the picture was taken was still much below the freezing point.

It is common practice at hydraulic plants, other than water-supply and hydro-electric stations, to let the sun thaw the plants out, next day, after frazil shuts them down! No effort is ever made to start ordinary mills up again during the same night that frazil shuts them down. With the operators of water, electric light and power services, however, other practices must of necessity obtain. The work of attempted relief is immediately begun. The members of the medical profession are not alone in having their night's rest disturbed.

Fig. 8 shows how relief from frazil attacks was afforded to the hydro-electric power plants in the Ottawa district during the two decades preceding the winter of 1905. A simpler and speedier method has since come into use at a majority of these and some other plants. When the water-wheel gates became frozen, the chutes clogged up, the penstocks filled, and, the racks blocked with frazil, it was formerly necessary for workmen to remove these icy accumulations by hand, or, to wait for next day's sun. As the frazil was crystallized as soon as it came into contact with the cold air, it was necessary to break it up with bars and axes before it could be taken out of the wheel pit. More than half the accumulation of frazil from this wheel pit had been removed when the picture was taken. After the ice was removed one of the following courses had to be adopted to loosen the gates which were still frozen to the wheel-cases: — (1) Either liberal doses of brine had to be applied to the gates, or, (2) a fire of oily waste and kindling wood had to be built around the wheel-case for the purpose of actually melting the ice and loosening the gates. Steam was sometimes used for melting the ice when it was available.

This ice-cleaning-out and ice-melting process usually occupied from three to five hours, the length of time depending upon the amount of ice to be removed, and, the difficulty of getting down and up the head gates or stop logs;—the latter, when put down, frequently froze in position and another difficulty was thus placed in the way of quickly restarting the plant.

It is almost out of place to mention that absolute continuity of supply is a necessity in connection with electric light and power services, and that a shut-down of *one minute's* duration is an unpardonable occurrence. Keeping this point in mind consider the effect of a *five-hour* or a *fifteen-hour* shut-down! These lengthy shut-downs came

Fig. 8.—Horizontal Water Wheels Overwhelmed by Frazil. Plant Shut Down. Workmen Removing Ice.

along, however, almost as regularly as winter during some 20 years of my experience. Shut-downs by frazil constituted 85 per cent of all the shut-downs during this long period and, it often happened that the operators of neighbouring industrial power plants had the satisfaction of getting their works started next morning with the aid of nature's remedy —the heat of the sun—just as soon as the others who had laboured all night.

It has long been generally recognized that the rising sun brings almost immediate relief to a plant frozen up with frazil. This was perhaps the first lesson in regard to relief from ice troubles that came to my attention. It was well known that before any *appreciable* rise in water temperature occurred, in the morning, water-wheels that had been completely shut down for hours immediately started running again.

The second lesson that I learned in connection with the frazil question was in regard to the necessity of keeping the vulnerable parts of water power apparatus protected from the action of the cold air.

For a number of years I noted the operation, and the annual shutting down, of a great number of plants, and I early became convinced that water wheels protected by *wooden racks* were better able to withstand frazil attacks than those protected by iron racks. This conviction —"theory" some called it—was confirmed as time went on: it was *often* supported by actual occurrences. In addition to these observations, I frequently encouragingly joined the beaten ice rakers—but only for brief periods at a time, because raking ice in the path of a blizzard is not an attractive occupation. With rake in hand I found that frazil could be removed from wooden racks very much as plastic mud can be scraped from one's boots, but, that it requires much more physical effort to detach frazil from a metal rack. Frazil actually crystallizes on a metal rack.

Why these different conditions in regard to iron and wooden racks obtain will be better appreciated by another glance at Fig. 3. As may be noted, a large area of iron rack projects into the air. When frazil is being formed the temperature of the air is frequently down to 0° F.—sometimes to —20° F. When frazil is being formed Dr. Howard T. Barnes has shown that the water's temperature actually goes a few thousandths of a degree below the freezing point. A note of the temperatures of the air and the water has been made upon this drawing, Fig. 3, so that they will be better impressed upon the mind. Assuming that the air temperature during a frazil attack is down below zero (0° F.) and that the water is just at 32° F.—at the freezing point. Is not this a picture of an ideal ice-manufacturing arrangement? Here is water just at the freezing point—perhaps a thousandth of a degree below it—just ready

to crystallize. Here is a cooling device—metal bars in the winter wind —often 50° or 60° below the freezing point—with an unlimited amount of nature's energy behind it, lowering the temperature of the iron rack and, by conduction, of the water surrounding the rack. The design of artificial ice-making plants is quite similar to this.

The necessity for a blacksmith to use tongs for the protection of his hands from the heat of the iron which he is fashioning is an old and well-known illustration of the heat conducting property of iron. On the other hand wood is such a poor heat conductor that a wooden rack has practically no cooling effect on the water and, consequently, frazil does not *crystallize* upon a wooden rack as it does upon an iron one.

The tail races of some power plants are also left exposed to the action of cold air, as shown in Fig. 3, and the temperature of the heavy metal draft tubes becomes lowered by the surrounding air. By conduction the water-wheel's whole case becomes chilled and its temperature is probably several degrees below the freezing point. My experience has been that these exposed or *neglected* plants *are* more susceptible to frazil troubles than others which are protected from the air, and these points of explanation, as to the cause, are such very reasonable ones that they are now agreed to by all who have given this subject serious consideration. As the temperature of the water itself never falls very low, it always stays within a few thousandths of a degree of the freezing point—and as water has such poor heat conducting qualities—about 120 times less than iron—it is most desirable, in my opinion, to keep the metal completely covered by this *warm* (comparatively speaking) water "blanket" rather than leave it exposed to the action of the cold air which may be 70 degrees below the freezing point.

The foregoing statements illustrate my mental attitude in relation to the frazil question at the time when I was fortunate enough to pick up a paper entitled: "Ice Formation and Precise Temperature Measurements," written by Dr. Barnes to whose work reference has already been made. The reading of Dr. Barnes' work filled me with a desire to carry out some experiments, and, these experiments—carried out in the face of much adverse criticism, absolutely no encouragement, and, some ridicule—were successful beyond the dreams of hope or imagination. They may be summed up with the statement that a set of water wheels overwhelmed by frazil, in the condition of that illustrated in Fig. 8, can, by the simple opening of a steam valve and the application of a little heat, be cleared of frazil in a few *minutes*. (It formerly took a greater number of hours, as pointed out above.) By the earlier application of a little heat, frazil will *not* accumulate around them at all, and the plant can be kept in continuous uninterrupted operation.

In Dr. Barnes' work, he emphasized a point with which I was familiar, i.e., that river water *remains just at the freezing point* all winter—as illustrated in Fig. 2*a*. He went further than this, however. He showed that water temperature variations from the freezing point *frequently* occurred in the winter and that they *were measurable*—in *thousandths* of one degree! His work was made possible by the aid of a Callendar thermometer which will measure a temperature variation of 1/10,000 of a degree with accuracy. Fig. 8*a* shows the relative sizes of a Callendar thermometer scale and a mercury thermometer scale.

Dr. Barnes discovered that the water's temperature in the Lachine Rapids where his work was carried out was sometimes 32.001° F., and sometimes 31.999° F.! He noticed that a change of a couple of thousandths of a degree, from one side to the other of the freezing point, was —to use his own language: "accompanied by tremendous physical effects." Frazil was made in immense quantities, after dark or on a cloudy day, if the change in water temperature was towards the negative side of, or below, the freezing point; and anchor ice was compelled to *loosen* its grip on the bed of the stream if the water became warmed to the extent of a thousandth of a degree on the positive side of the freezing point by the heat of the *sun*.

The beneficial effects of preventing the cold air from chilling the metal parts of hydraulic equipment had long been well-known to me, and the action of the heat of the sun in relieving frozen plants before any appreciable, or, as we thought, *measurable*, rise in water temperature occurred, was also well-known for many years. No one, however, at least to my knowledge, had ever conceived what delicate or almost infinitely minute water temperature changes actually take place in our streams in winter until Dr. Barnes made this point so beautifully clear when carrying out his investigations for the Montreal Harbour Commissioners. The light shed upon my study of the Ice Question by the publication of Dr. Barnes' work opened up the following line of thought: Energy measured in millions of horse power *may* be necessary to change the water used in a power plant from the solid to the liquid state without raising its temperature; hundreds of thousands of horse power *may* be required to raise the temperature of all this water one degree; but, the hydraulic power plant operator has nothing to do with either of these problems. His duty is to prevent the temperature of his apparatus from being lowered to the freezing point—to keep this temperature 1/10,000 of a degree on the positive side of the freezing point—and when this is done frazil will then have no inclination to adhere to the apparatus.

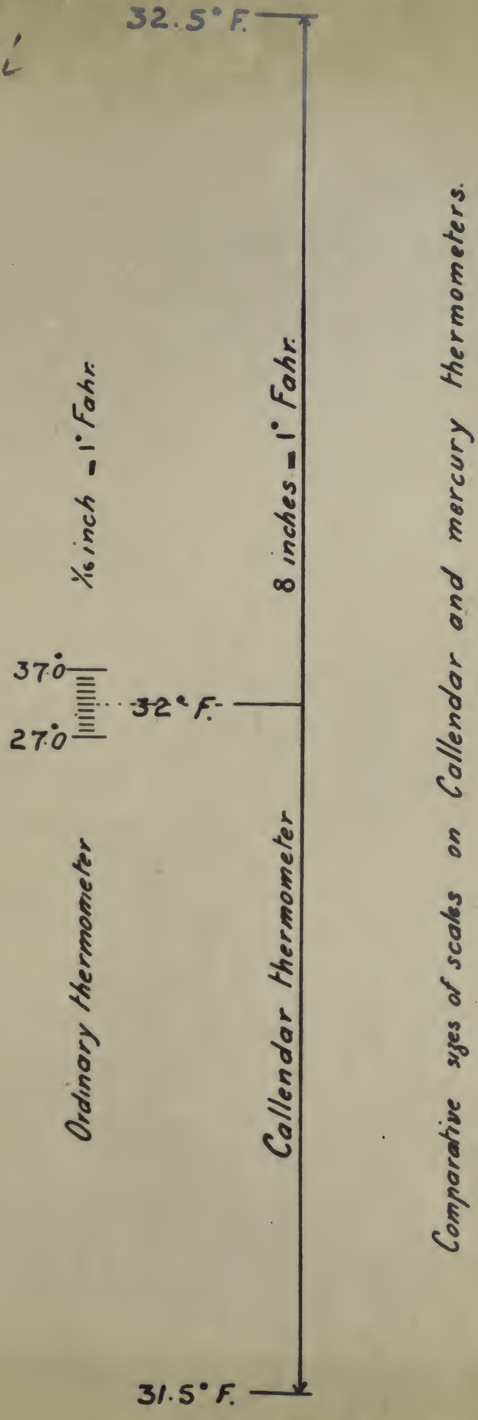

32.5° F.
1/16 inch = 1° Fahr.
8 inches = 1° Fahr.
37.0°
32° F.
27.0°
Ordinary thermometer
Callendar thermometer
Comparative sizes of scales on Callendar and mercury thermometers.
31.5° F.

FIG. 8a.

Up to this time no one, so far as I could learn, had ever attempted to heat the apparatus so that ice would neither form upon it nor stick to it if it floated along. Suggestions which embodied the heating of the water in a stream or the melting of ice were always treated as preposterous by hydraulic engineers and their attitude is readily accounted for by an examination of some figures in connection with these proposals.

These figures are illustrated by the three cubes in Fig. 9 and by the

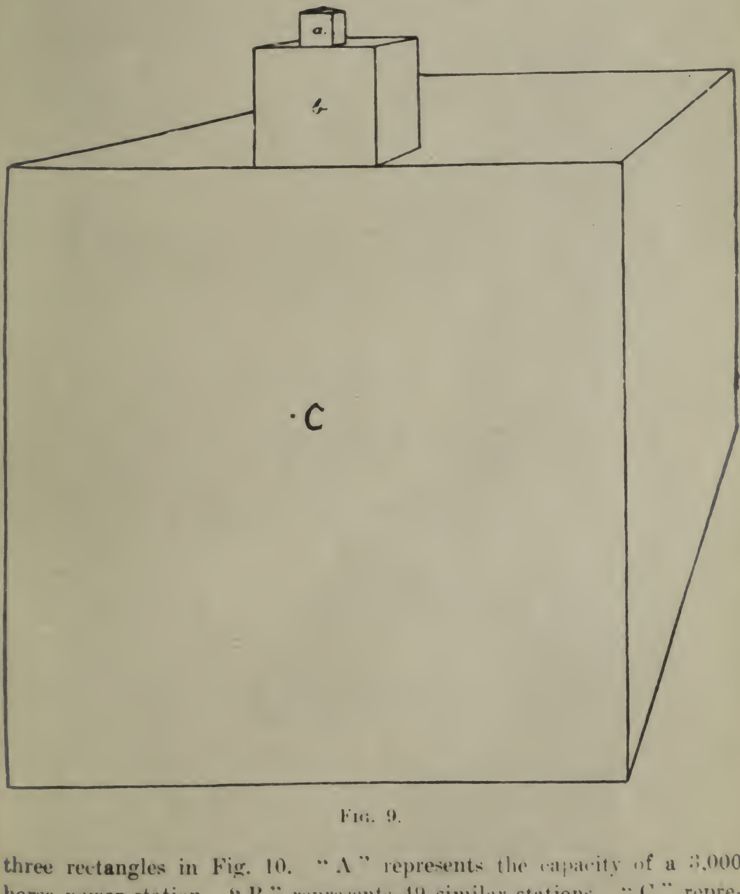


Fig. 9.

three rectangles in Fig. 10. "A" represents the capacity of a 3,000 horse power station. "B" represents 49 similar stations. "C" represents 7,000 stations as large as "A".

If it were proposed to raise the temperature of the water passing through station "a" in Fig. 9 *one degree* Fahr. the operation would require all the output of station "b," i.e. 49 times as much energy as "a" can produce.

If all the water passing through station "a" had to be changed from the solid to the liquid state—without any rise in temperature—this operation would require the total output of 7000 stations as large as "a." This last amount of energy is represented by cube "c."

These facts are also illustrated by the squares in Fig. 10.

For explanation of Fig. 10 see note following Fig. 9.

Fig. 11 illustrates a new method of dealing with the frazil question. Fig. 11 is a picture of a frazil-combatting scheme which has given more

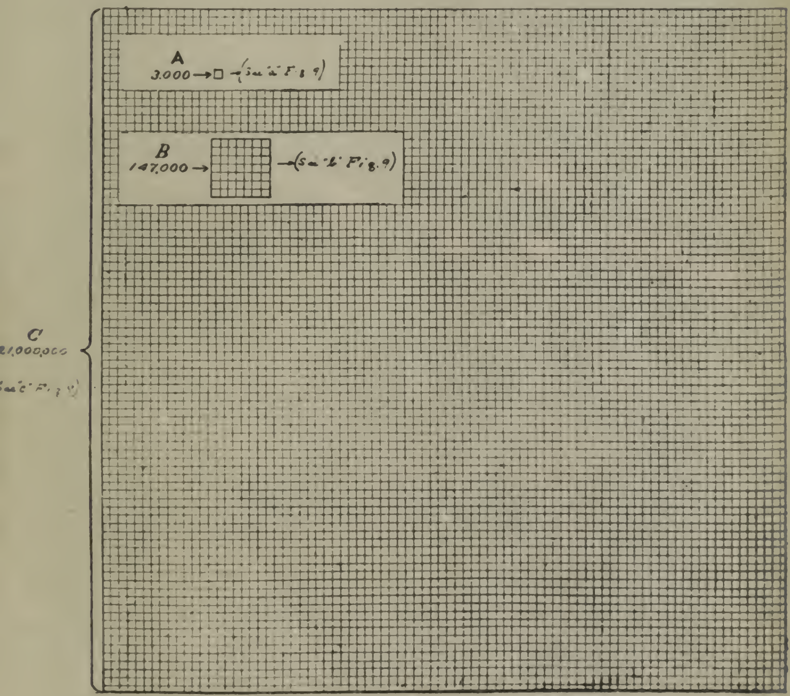


Fig. 10.

beneficial results than one not personally conversant with the details of its successful operation can readily imagine. First of all, the action of cold air is carefully excluded from every part of the plant. This, in my opinion, is a point of vital importance and one that should receive careful attention. Secondly, heat is applied to the parts of the plant to which frazil is likely to adhere, i.e., at the rack, and at the controlling gate. This (Fig. 11) is a picture of an installation at Ottawa. This rack never blocked up with frazil while it was thus equipped. This wheel has not choked up with frazil and this gate has never been uncon-

trollable since 1905 when it was first equipped. Some 30 water-wheels are now rigged up in this manner and are operated with similar success while others close by, not so protected, have been tied up for days at a time. The governors in the first station so equipped have not only controlled the variations in load which occurred on the light and power systems supplied from this station, but they have also, on innumerable occasions, taken care of the variations in load on a calcium carbide plant, on a cement plant and on a street railway plant while the controlling

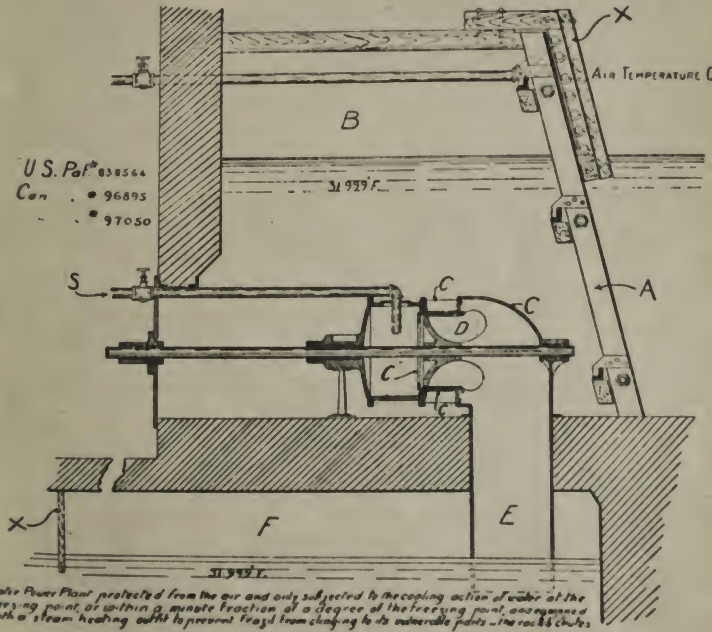


Fig. 11.

gates of the three latter plants were all frozen stiff for days and nights together. The generators in all these stations were operated in parallel and they all, with the exception of the one in question, were time and again either shut down altogether or else had to operate with a constant load upon them because their controlling gates were frozen and could not be moved.

The heating arrangement here shown may not be considered an economical one. Yet more than one ton of coal was never consumed in 24 hours in order to keep a plant with an output of 3,000 horse power in continuous operation at times when frazil shut

down all other wheels within ten miles of it. To supply 3,000 horse power from a steam plant requires about 6 tons of coal per hour calculating at the conservative figure of 4 lbs. per horse power per hour! By comparison with this the ice combatting plant shows great economy. Fig. 12, the two cubes, serves to illustrate this point.

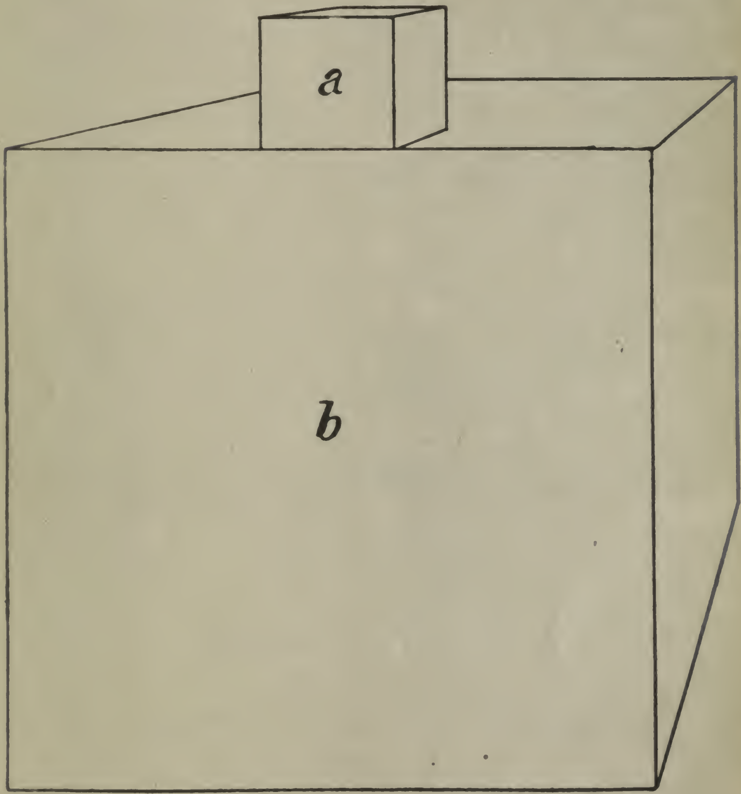


FIG. 12.

In Fig. 12:—"a" represents the amount of coal consumed in 24 hours in order to keep a 3000 h. p. hydro-electric station free from frazil. The coal consumed is 1 ton.

"b" represents the amount of coal consumed in a 3000 h. p. steam station in 24 hours. The coal consumed in the steam station amounts to 144 tons.

Some such arrangement as that shown in Fig. 11 has to be improvised for plants already in operation, and this simple scheme has worked very successfully.

A point that may prove of special interest is the fact that *last winter* was the *first winter* that the Ottawa Electric Railway Company, whose water wheels filled with frazil are shown in Fig. 8, have made use of a small steam plant for fighting frazil. *This* last winter was the *first*

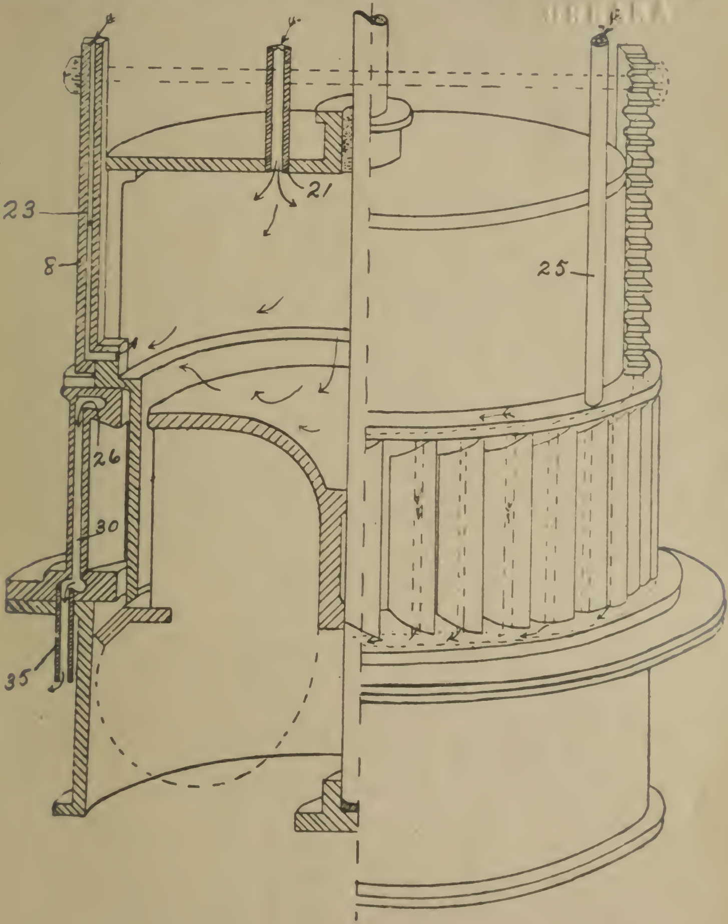


Fig. 13.

winter since this power plant was built that they did not have to chop the crystallized frazil out of their wheels by hand.

A more economical arrangement and one which may be incorporated in and provided for at new plants is along the lines illustrated in Fig. 13.

Fig. 13:—Canadian Patent No. 96895, and U. S. Patent No. 858564, shows a water-wheel designed to prevent ice from forming upon or adhering to the chutes and gate.

The chutes and parts of the case in Fig. 13 against which the ice and water flow are shown cored out (in the foundry) so that any heat bearing fluid may be kept in constant circulation through them when frazil is expected. Water-wheel cases are now being built after this pattern and it is expected that ice in any form will not adhere to them.

Besides the above work which is briefly described a number of experiments were also made in electrical rack heating. These were carried far enough to show that this method is practicable; 1/50 of 1 horse power-hour of electrical energy broke the bond between solid ice and a piece of iron rack.

Many engineers of mature experience who at first skeptically viewed the proposal to combat frazil with reasonable amounts of heat are now enthusiastic in regard to its feasibility. Bear in mind that while 1 British thermal unit is required for the purpose of raising the temperature of 1 lb. of water 1 degree Fahr. this same quantity of heat will raise the temperature of 1 lb. of iron about 9 degrees: and, when it is recalled that the temperature of the submerged or otherwise protected metal parts of the hydraulic equipment only require to have their temperatures kept the most minute conceivable fraction of one degree above the freezing point in order to prevent ice from adhering to them it may be seen that this scheme for combating frazil is a most reasonable one.

While dealing with the frazil question I may be pardoned for digressing for a moment in order to briefly mention some other water-power troubles. First there is the annual diminution of the water supply in our streams that occurs towards the latter part of almost every winter. This is, in my opinion, primarily caused by the cessation of surface drainage. In winter time, in the greater portion of this country, atmospheric precipitation takes place in the form of snow, instead of rain, and, consequently, many of the sources of our rivers receive no surface drainage and are dried up. Secondly there is the difficulty of securing a flow of water through comparatively shallow channels into many power plants on account of deep surface ice, to the under side of which frazil has become attached, completely blocking the channels. This condition coupled with the diminution of flow in a river is generally of greater moment than the summer drouth and is often called another "anchor ice" trouble. These troubles can only be relieved by the building of dams and the creation of immense storage reservoirs from which an equable steady flow may be obtained all the year round. Spring floods and summer and winter drouths annually recur. The flood in the

spring of 1908 was just a little worse than usual although it created much interest. A spring without a flood is, in my experience, an unusual one. In this connection some old newspaper clippings are interesting:—

From the *Ottawa Citizen* of May 21st, 1888—" Just twenty years ago"—I read as follows:—" The water in the Ottawa is now exceedingly " high and is still rising. The houses along the river at Gatineau Point " are still inundated, the occupants being obliged to use the upper por- " tion of their houses to live in, and in some cases have had to abandon " them altogether."

From the *Free Press* of May 16th, 1873—" 35 years ago"—the following extract is taken:—

" The water in the Ottawa river is now within a foot and a half of " its highest pitch. The falls are scarcely visible."

In March, 1908, the water power users did not have water enough to run one-quarter of their wheels and in May the output of their wheels was again similarly reduced by the flood! A little later and they will be short of water again. In order to show that the water shortage question, as well as the spring floods, is not entirely new, two more short extracts from the " Just 20 years ago" column are given:—

" *Ottawa Citizen,* August 30th, 1887:—Chaudiere lumbermen are " complaining of the low water. A remedy they think could be provided " by the construction of a dam."

" *Ottawa Citizen,* October 16th, 1887:—A man named Potvin has " accomplished the feat of walking across the Chaudiere Falls at the " brink of the big kettle. He found only about six inches of water."

Then turning to the newspaper files containing the winter records of each succeeding year one finds " Anchor Ice" blamed for " shutting down the Water Works Pump House," " reducing the Water Pressure," " stopping the cars" and " putting out the lights" when in reality anchor ice had nothing to do with these happenings. They were annually caused by frazil, and by the winter drouths, as explained above. " Anchor Ice" is a handy phrase and it will probably remain in use for a long time in spite of efforts to credit frazil with the record it has made.

When making estimates of the amount of water power available on a stream it should be known how little power is available, during periods of minimum flow, so that provision for these emergencies may be made. This information is just as important as to know how much power may be obtained during the period of normal and maximum flow. I have in mind a case where only from 15 to 20 per cent of the hydraulic machinery actually installed can be made use of during three months of every year.